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GIS AND TIME-SERIES INTEGRATION IN THE KENNEDY SPACE CENTER ENVIRONMENTAL INFORMATION SYSTEM[1]*

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ABSTRACT

The John F. Kennedy Space Center region is recognized as being biologically unique with a large number of federally listed threatened and endangered species within its boundaries. Aware that environmental management decisions require sound data NASA started the Ecological Program 14 years ago, within which an immense amount of environmental data has been collected.

Having realized that the amount of data collected would never be fully used without appropriate tools, the EP team decided to create a system aimed at storing all the data, including the appropriate tools for data analysis and exploration, the Mapping Analysis and Planning System (MAPS). In order to cope with the temporal, spatial and thematic dimensionality of the problem a 5-D approach was taken, objects and entities being characterized in a space-time-theme context. One of the major practical problems of this approach was the integration of space and time (basically a temporal GIS problem). The practical implementation is based on an ORACLE database server, with a geo referenced ArcView based interface coupled to specially developed time-series and image handling modules.

1.0 THE KENNEDY SPACE CENTER

The John F. Kennedy Space Center (KSC) region is recognized as being biologically unique with a large number of federally listed threatened and endangered species. Aware that environmental management decisions based on short-term data sets or information derived from other locations often prove erroneous, the National Aeronautics and Space Administration (NASA) started the Ecological Program (EP) 14 years ago.

According to the EP the Center's operational objectives are the "Protection, enhancement and preservation of the unique natural resources of Merritt Island as a requirement for activities at the Space Center". The EP is conducted to develop information necessary to define, assess and predict environmental problems that may result from activities at KSC in compliance with existing legislation and NASA commitments." (DYNAMAC, 1995).

During this period an immense amount of data has been collected, processed and analyzed; the data catalog developed in 1995 inventoried 93 different data sets, spanning the whole environmental dimensions: aerial (rainfall, temperature, air quality), terrestrial (wetlands, soil characteristics, land use, etc.), aquatic (water quantity and quality in the estuary), underground (groundwater quantity and quality), ecological (habitats, birds, reptiles, fish, manatees,) and environmental uses (facilities location and characterization, network characterization, fire data, pollution sources, solid waste sources, etc.). The diversity of data collected and the effort already invested in its processing make this collection quite unique.

2.0 MAPS

Having realized that the amount of data collected would never be fully used without appropriate tools, the EP team decided to create a system aiming at storing all the data, including the appropriate tools for data analysis and exploration. After a detailed analysis process the team proposed the creation of the Mapping Analysis and Planning System (MAPS). Almost simultaneously NASA decided to move from a scattered data approach to a centralized database approach.

MAPS has three major objectives: (i) insuring that all data are properly validated and safely stored in a central database; (ii) implementing a transparent data harvesting process, by means of which data introduction in the database is carried out as part of daily tasks and not as one more task; (iii) enabling an integrated view of the whole database, enabling experts from different fields to integrate as much data as they wish in their analysis.

3.0 THE BASIC PRINCIPLES

3.1 THE FIVE DIMENSIONS

A closer look at most environmental phenomena shows that we are dealing with five different dimensions: the location in space, expressed as a set of 3 coordinates -latitude, longitude and altitude-, the position in time and the particular phenomena or theme being analyzed. The goal of the EP is to collect data in this five-dimensional world, in the most efficient possible way. It is evident that one cannot collect data continuously in all dimensions. Sinton (Sinton, 1978) states that conventional data forms do not measure all three components concurrently: one is fixed at a constant value, a second is controlled to a range of values, and only then the third can be measured on an interval or ratio scale.

The need to freeze the thematic axis, measuring one or a few phenomena at a time, is obvious and determined by the type of measurement devices we have. When we freeze the three spatial dimensions, fixing the spatial location of the measurement, we are actually measuring a time-series of a given phenomena in a given measurement station. Measuring climatic variables in a meteorological station is a good example of this approach. By installing many meteorological stations we can extrapolate the spatial variation of rainfall or temperature. In a weather radar the temporal dimension is frozen, and the surface variation of rainfall in the area covered by the radar is obtained. Ocean temperature and the other remote sensing based variables are examples of this type of measurement.

The Euler model for fluid dynamics can help visualize a measurement in which neither time nor space are constrained: the measurement system follows a particle, and at each time determines the current position, the time and the value of the attributes being measured. Manatee tracking is a good example of this type of measurement: the radio signal installed in the animal may be coupled to a GPS and the three-dimensional position of the animal can be determined at

exact moments in time; if the device has additional probes, the temperature of the animal or the heart-beat can be measured as well.

3.2 PHYSICAL MAGNITUDES, MEASUREMENTS AND COVERAGES

In order to design a system capable of handling the diversity of data found at KSC it was necessary to start from the basic foundations. Physical Phenomena (PP) are the events surrounding us; measurement is based on the definition of the Physical Magnitude (PM) associated to the phenomena, which are subject to measurement. The process of measuring these PM implies the definition of the type of measurement. Most authors agree on the classification of measurement methods in 5 classes, MAPS including data of all five types: Classification (land cover), Ordination (classification of impact of human activities based on degree of incidence), Enumeration (bird counting), Metrication (temperature, water quality, etc.) and Derived (flow, when derived from water level gage), (Clark, Hosking, 1986), (Burrough, 1986).

PP and PM are theoretical constructs; in order to measure them we have to use parameters. The same PM can be measured in many different ways, using different measurement techniques and the final result can be expressed in different metric units, which implies that a single PM may be expressed in practice by many different parameters. To fully characterize a parameter it is necessary to specify: the PM being measured; the dimensions in the fundamental units of the International System of Units (SI); the temporal resolution; the transformation method; the units in which it is expressed; the measurement method description, including type of measurement, description of the method, physical granularity of the measurement; and the precision.

Measurements are associated to Measurement Entities (ME), which are geographic objects to which the PM is associated. If the parameter is air temperature, then the geographic object is the measurement station (a 1-D geographic coverage); if the parameter is bird count then the geographic object is for instance a polygon defining the limits of an island (a 2-D geographic coverage). If the parameter is rainfall measured by a weather radar, then the measurement itself is a grid, with well defined geographic characteristics. MAPS uses the concept of Measurement Coverages (MC) to associate any geographic object as the source for a given measurement, in a general theoretical framework.

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4.0 COMBINING GIS, TIME-SERIES AND IMAGES

4.1 TEMPORAL GIS

Setting MAPS on this theoretical definitions of measurement allows the user to work both at the PM and the parameter levels, and combines the five types of measurement, thus enabling a high level of data integration. As each measurement is defined in the 5D space, the integration of space and time is taken care of at the conceptual level, thus introducing MAPS in the temporal GIS arena. This is a complex field, where much research is still required. Research proceeds in various directions, ranging from the development of the fundamental theory (Raper, Livingstone, 1995), to the visualization of 5-D processes (Hibbard et al., 1995) and the practical implementation of the basic concepts (Langram, 1993). Efforts span also the software vendors, with the implementation of multidimensional databases (Waters, 1995; Oracle, 1995).

4.2 THE MAPS DATABASE

The core of the MAPS system is an ORACLE based database server, where data are stored. At present only 1-D geographic objects are stored inside the database; the others are stored as references to Arc/Info coverages. In the near future full integration is envisioned, as tools such as SDE by ESRI and Multi-Dimension by ORACLE become available. The theoretical constructs of MAPS were programmed as ORACLE packages. Together with its accompanying tools and interfaces this component of MAPS was designated Time Series Framework and Tools (TSF&T).

In short, the concepts behind the TSF&T are:

- data stored in the TSF&T are measurements of a number of PM's, ranging from rainfall intensity to mercury concentrations, including animal counts or seagrass surveys;

- TSF&T stores multiple types of measurements: metric (temperature or rainfall) and derived (flow computed from a rating curve), enumeration (number of birds in a given place), classifications (vegetation in a given area), and ordinations (sequence within an event);

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- the measurement method, the temporal and spatial resolutions, and the units used to express the result determine the parameter associated with each measurement;

- all measurements are associated with a Measurement Entity (ME), which is geo-referenced;

- the ME can be a point (sampling station or rainfall measurement site), a line (crocodiles in a ditch or a seagrass transect), or a polygon (bird counts on a small island).

4.3 THE INTERFACE

Once data are stored in the TSF&T database it is indispensable to have a proper interface, to allow the user to access and process data. Given MAPS GIS nature this interface must be georeferenced. The interface is based on two tools: the Time Series Browser and the ArcView Time Series Integrator.

The TS Browser is a window to the ORACLE database, allowing the user to select themes, browse through the themes, checking the available data, select the data, and do any preliminary processing of those data. As the result of the selection process, the user gets a set of data that can be analyzed graphically, presented in tabular form, or viewed spatially in the ArcView Time Series Integrator.

The ArcView Time Series Integrator application is developed in AVENUE, using ArcView. Besides the usual functionality of ArcView2, it includes new capabilities, namely: communication with the Browser, dynamic creation of maps with point features (by direct communication with the ORACLE database), and dynamic query to the Oracle database. Another set of added capabilities uses the functionality of Arc/Info and GRID in a client server mode, thus allowing users without Arc/Info training to do the sort of GIS analysis usually limited to more experienced Arc/Info users. Spatial analysis related to time-series integrated in the tool include: for a selection of ME and selected time-series (TS), with appropriate statistical treatment, compute the Voronoi Thesselation, area totals, isolines and fit a surface. From the same interface the user may select images, related to ME.

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5.0 CONCLUSIONS

This paper reviewed the foundations of MAPS, the KSC Environmental Information System, in the perspective of the development of its spatio-temporal capabilities. The sound theoretical foundation adopted is expected to break the barriers between different areas of expertise, thus allowing NASA to take full advantage of the diversity of data collected during the last decade.

Work will continue on the practical application of the system to natural resources management in KSC. Research will go on, namely in the integration of network based spatial data with real spatial data, like weather radar, in the pursuit of a real spatio-temporal GIS and the development of user friendly environmental decision support capabilities.

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